The distribution of lightning channel lengths in northern Alabama thunderstorms

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1. INTRODUCTION

Lightning is well known to be a major source of tropospheric NO_x, and in most cases is the dominant natural source (Huntreiser et al 1998, Jourdain and Hauglustaine 2001). Production of NO_x by a segment of a lightning channel is a function of channel segment energy density and channel segment altitude. A first estimate of NO_x production by a lightning flash can be found by multiplying production per segment [typically 10^4 J/m; Hill (1979)] by the total length of the flash's channel. The purpose of this study is to determine average channel length for lightning flashes near NALMA in 2008, and to compare average channel length of ground flashes to the average channel length of cloud flashes.

2. METHODOLOGY

Raw VHF source data is obtained from NALMA. The VHF signals are then grouped into flashes using McCaul et al's (2009) clustering algorithm. Flashes defined by less than 100 VHF sources were removed, thus eliminating so-called "singleton events" that consist of a single, isolated VHF source. Furthermore, flashes occurring more than 120 km from the centroid of NALMA were also removed, to eliminate range errors. In order to help eliminate spurious noise from non-lightning sources, to help remove VHF lightning sources that are not located on the channel (i.e., lower amplitude sources that fall well outside the physical channel), and to avoid large overestimates in the channel length computation a 16 dBW minimum power constraint was placed on signals read into the program. Once all of these filters are applied, the algorithm connects each source with its nearest neighbor in three-dimensional space, beginning at the highest altitude source.

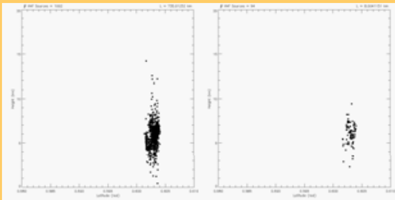

Figure 1: A lightning flash with all VHF sources displayed (left), and the same flash with only sources above 16 dBW displayed (right). Filtering out the low power signals allows the location of the main lightning channel to be more accurately displayed and measured.

3. ERROR SOURCES

1. The VHF sources themselves are associated with position errors as a function of distance from the LMA network. These errors are characterized in Koshak et al (2004), and are minimized by only counting flashes within 120 km of the centroid of the LMA network.
2. The program only looks at flashes defined by at least 100 VHF sources. This would have the effect of excluding "short" lightning flashes, and overestimating average channel length.
3. The program then only uses VHF sources within a given flash that have a strength greater than or equal to a user-defined value. This changes from one storm to the next, but always ranges between 16 and 20 dBW. Setting the minimum power too high or low would lead to an underestimate or overestimate of average channel length, respectively. As such, the minimum power is chosen to be a value that results in an average channel length between 5 and 7 km, as defined in Uman (1984) and Rakov and Uman (2003).
4. Smoothing of sources to the nearest 50 meters would introduce a random error that decreases with increasing flash count.
5. VHF sources are connected to each other based on which pair of points produces the smallest nonzero segment length. This is generally supported but not mandated by the physics. It potentially leads to a small underestimate of channel length.
6. If the nearest distance between two sources is greater than 500 m, the channel segment is not counted at all. The purpose of this is to remove the contribution of isolated VHF sources, which would otherwise lead to a large overestimate of channel length. If the sources were actually part of the channel (unlikely), an underestimate of channel length would result.

4. RESULTS AND SUMMARY

The average channel length of 5.5 km compares favorably with Uman's (1984) estimate of 5 km, as well as Rakov and Uman's (2003) estimate of 7 km, the latter referring specifically to Florida lightning.

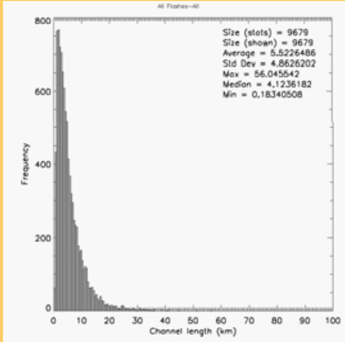

Figure 4: Histogram of flashes in 2008. A total of 9679 flashes met the criteria for number of sources and proximity to the NALMA centroid. A distribution of channel lengths from several storms is intended to replace the "one size fits all" channel length used in CMAQ's lightning NOx calculations.

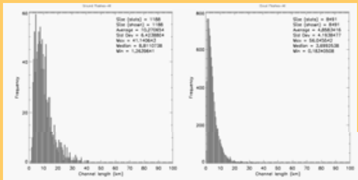

Figure 5: The distribution of ground flash channel lengths (left) and cloud flash channel lengths (right). Cloud flash lightning occurs more frequently, while on average ground flashes are greater in length.

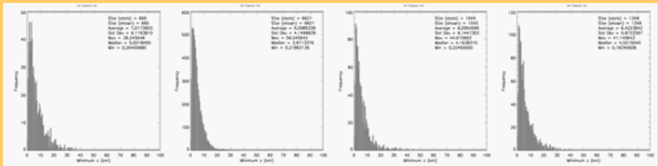

Figure 6: From left to right, the distribution of channel lengths for all flashes from spring, summer, autumn, and winter. Lightning is most frequent in north Alabama during the summer.

5. REFERENCES

Hill, R.D., 1979: A survey of lightning energy estimates. *Rev. Geophys. And Space Phys.*, **17**, 155-164.

Huntreiser, H. et al., 1998: Transport and production of NO_x in electrified thunderstorms: Survey of previous studies and new observations at midlatitudes. *J. Geophys. Res.*, **103**, D21, 28,247–28,264.

Jourdain, L. et al, 2009: Lightning NO_x emissions over the USA investigated using TES, NLDN, LRLDN, IONS data and the GEOS-Chem model. *Atmos. Chem. Phys. Discuss.*, **9**, 1123-1155.

Koshak, W.J. et al., 2004: North Alabama lightning mapping array (LMA): VHF source retrieval algorithm and error analyses. *J. Oceanic and Atmos. Tech.*, **21**, 543-558.

McCaul, E.W., S.J. Goodman, K.M. LaCasse and D. J. Cecil, 2009: Forecasting lightning threat using cloud-resolving model simulations. *Weather and Forecasting*, **24**, 3, 709-729.

Rakov, V. A. and M. A. Uman, 2003: Lightning: physics and effects. Cambridge University Press, Cambridge, United Kingdom, 698 pp.

Uman, M.A, 1984: Lightning. Dover Publications, Mineola, New York, 192 pp.

6. ACKNOWLEDGEMENTS

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